RMRS Rocky Mountain Remediation Services, L.L.C.
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PROCEDURE

SURFACE GEOPHYSICAL SURVEYS

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USE CATEGORY 2

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1.0 PURPOSE

This document describes procedures that will be implemented for all surface geophysical surveys performed at the Rocky Flats Environmental Technology Site (RFETS). These procedures will be followed by Rocky Mountain Remediation Services (RMRS) or contract personnel conducting geophysical surveys unless otherwise instructed by the RMRS project manager.

Geophysical techniques such as those described within this document measure variations in the physical properties of subsurface materials. For example, they are useful for identifying interfaces indicated by changes in seismic velocity, density, resistivity or conductivity, fluid content, degree of fracturing, soil or rock thickness, or linear features such as faults or dikes. Geophysical techniques can also delineate man-made subsurface features (such as pipelines or buried tanks, drums, and trenches) as well as subsurface contamination. This document specifically addresses shallow electromagnetic (EM), ground penetrating radar (GPR), self-potential (SP), magnetic, and time-domain electromagnetic metal detection techniques. This document describes administrative requirements and geophysical data reduction and analyses that will be used for field data collection and documentation in the course of performing geophysical surveys.

2.0 SCOPE

This document, which supercedes Procedure No. GT.18, constitutes a standard operating procedure (SOP) that applies to all Rocky Mountain Remediation Services (RMRS) personnel and subcontractors conducting surface geophysical surveys at RFETS.

This SOP has been written to comply with and complement several other procedures that are directed towards using geophysical techniques to clear locations of proposed intrusive activities. Those procedures - RMRS/OPS-PRO.102, Borehole Clearing, and Kaiser-Hill procedure MAN-072-OS&IHPM – will be followed, as appropriate, whenever the objective of the geophysical survey is to clear locations that have been selected for intrusive activities.

Other instruments and/or techniques may be employed in addition to the approved geophysical techniques described in this SOP. For example, advances in technology may lead to the use of new, scientifically based geophysical methods that replace or complement the methods described herein. However, the RMRS project manager prior to its use must approve use of any additional method. If the RMRS project manager approves the use of such a new technology or instrument, he or she will document the use and advantages of the new method and will write and submit a Document Modification Request (DMR) within 48 hours of the implementation of the new method in accordance with procedure 2-EO4-ER-ADM-05.07. This DMR will then be appended to this SOP.

3.0 REQUIREMENTS

3.1 Personnel Qualifications

Personnel performing these procedures are required to have completed the initial 40-hour OSHA classroom training that meets Department of Labor Regulation 29 CFR 1910.120(e)(3)(i), and must maintain a current training status by completing the appropriate 8-hour OSHA refresher courses. Personnel must also complete and be current on any other site-specific training that may be required to perform these activities at RFETS, and are required to have a complete understanding of the procedures described within this and other related SOPs.

Only qualified personnel will be allowed to perform geophysical surveys. Required qualifications vary depending on the activity to be performed. In general, qualifications are based on education, previous experience, on-the-job training, and supervision by qualified personnel. All staff involved with the geophysical surveys shall be trained geophysicists or trained personnel with a significant amount of geophysical field experience, and shall have previous experience with data collection and interpretation procedures for the methods used. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project QA files.

RMRS personnel will supervise geophysical surveys. The subcontractor project manager or task leader will ensure that all project personnel follow this SOP and any other appropriate procedures.

3.2 Equipment

Because equipment requirements vary depending on the geophysical methods to be used, equipment requirements are described in general terms within the Instructions section for each method. Instrument-specific instructions are not included in this SOP because the particular instruments in use at RFETS may change as new technologies and instruments become available. Particular instruments are named by way of providing examples that are acceptable for use at RFETS. The manufacturer's instructions will be followed at all times when using geophysical instruments. Any equipment brought on site or leaving RFETS must be verified to be contaminant free.

4.0 INSTRUCTIONS

Project work plans will describe the use of geophysical techniques, the objectives of the subsurface investigation, and the expected results. The following preliminary information regarding the survey site must be obtained:

- Subsurface geologic, hydrogeologic, and soils information for the investigation site, the area, and the region;
- Known hazards that pose a threat to the safety of field personnel;
- Locations of electrical and telephone utilities obtained from site utility plans, and their potential influence on survey results.

Based upon this preliminary information and the project-specific objectives and subsurface information required, RMRS and subcontractor personnel will design an appropriate geophysical program.

Geophysical tools that are employed at RFETS include electromagnetic (EM) techniques (including line locators), magnetic locators, time domain electromagnetic metal detectors (TDEM) and ground penetrating radar (GPR). Magnetic, EM and TDEM surveys can be used to identify areas where subsurface metal objects may be present. These techniques delineate contrasts in the electrical conductivity or magnetic properties of metallic objects and subsurface materials. GPR can be helpful in locating metallic and non-metallic objects as well as other subsurface features, as it detects variations in the subsurface dielectric constant. Subsequent sections describe specific procedures for each technique.

4.1 Electromagnetic

4.1.1 *Introduction*

Electromagnetic (EM) methods measure the electrical conductivity of subsurface soil, rock, and groundwater, which depend on the subsurface soil or rock composition, porosity, permeability, and the conductivity of fluids filling the pore spaces. EM methods can be useful in assessing the depth and orientation of bedrock; lateral variations in soil and rock and the extent of paleochannels; lateral and, in some instances, vertical extent of contaminants; and the presence of ferrous and nonferrous metals.

EM instruments operate by inducing an electrical current in the subsurface. A small alternating current passing through a transmitter coil produces a primary, time-varying magnetic field in the ground. Through inductive coupling, the primary magnetic field produces small eddy currents in the subsurface which, in turn, create their own secondary magnetic field. The receiver coil senses both the primary and secondary fields. Linear changes in magnitude and phase of the individual currents are related to the terrain conductivity. These changes in the individual currents are converted to voltages and output as ground conductivity values, which can be recorded manually by a strip recorder or by a digital logger. Depth of investigation increases as the separation between the transmitter and receiver coils increases. By using several different coil spacings, several penetration depths can be achieved. All conductivity values are subsequently plotted on a map so that their variation throughout the site can be analyzed.

This section specifies procedures for EM surveys using shallow penetration systems such as the EM-31, EM-38, and EM 34-3. These instruments permit two different coil orientations, the horizontal dipole mode (coils vertical coplanar) and the vertical dipole mode (coils horizontal coplanar). The two modes produce different penetration depths.

4.1.2 *Survey Design*

4.1.2.1 Field Equipment

The following equipment is needed to complete an EM survey:

- Geonics EM-31, EM-38, or EM 34-3 terrain conductivity system or equivalent (choice based on depth penetration required)
- Digital logger and/or analog strip recorder (when data collection is over large grid area)
- Appropriate health and safety equipment
- Wood stakes or lath
- Flagging
- Field logbook
- Black waterproof (permanent) pens

4.1.2.2 Field Procedures

A standard field procedure for an EM survey is described below. Two preliminary steps must be completed first.

- Design field parameters appropriate for the purpose of the survey (consider depth of investigation, whether EM-31, EM-38, or EM 34-3 is used, coil spacing, coil orientation, and station spacing).

- Survey the baselines and place lath or wooden stakes at 100-foot intervals along each line. Along each baseline, survey the locations of endpoints of each grid line using a tape. Mark these endpoints with lath, wooden stakes, or nontoxic biodegradable paint. Using a tape and compass, survey the location of each station along the grid lines and mark each location with flagging or nontoxic biodegradable paint. Mark the coordinates of each station according to the coordinate system used for the survey of the baselines. Transfer line and station locations to the appropriate base map.

Design of appropriate field parameters must consider the following.

- The coil spacing should be 0.75 to 1.5 times the required depth of penetration depending on whether the instrument will be used in the vertical or horizontal dipole mode. Choose an instrument that can reach the required penetration depths (see Table PRO.104-1)

- Spacing between stations determines the degree of resolution. A spacing of 10 to 100 feet is commonly used; however, spacing as small as 2 feet may be required for extremely shallow targets or to aid resolution in very complex environments. The overall survey objectives and the resolution and maximum depth required will determine the station spacing.

- In grid areas, intraline spacing affects resolution. A spacing of 10 to 400 feet is commonly used, but smaller spacing may be used to increase resolution and attain the overall objectives of the survey.

- Three or more anomalous readings are required to define an EM anomaly.

- Background conductivity noise caused by cultural interference (e.g., from overhead or buried power lines and steel-cased monitoring wells) must be evaluated for its potential effect on an EM survey. High noise levels can make interpretation difficult and hide anomalies. In some instances, it can make data collection and interpretation impossible, and may require the implementation of a TDEM survey if the objective includes the location of metallic objects. Actual background noise must be considered when collecting and interpreting the EM data.

- Background conductivities of the investigated materials, including groundwater if appropriate, should be estimated to aid in identifying anomalies. Where possible, determine conductivities for site-specific groundwater by analyzing samples from monitoring wells adjacent to the survey area. Wells should be analyzed as close to the actual survey date as possible to ensure that the pore water conductivity determined represents conductivity at the time of the survey.

TABLE PRO.104-1

EM INSTRUMENT MODE AND PENETRATION DEPTHS

Instrument	Coil Spacing	Approximate Depth of Penetration (feet)	
		Horizontal Mode	Vertical Mode
EM-38	Fixed — 1 meter (3.28 feet)	2.5	5
EM-31	Fixed — 3.66 meters (12 feet)	9	18
EM-34-3	Variable — 10 meters (32.8 feet)	25	49
	20 meters (65.6 feet)	49	98
	40 meters (131.2 feet)	98	197

A standard field procedure for conducting an EM survey is described below.

1. Review site utility plans and perform a field inspection along the proposed survey lines. Check for overhead wires, manhole covers, buried cables, buried gas line indicators, and cased monitor wells. Have Excavation Specialists confirm the presence of telephone and utility features. Note the features in the field logbook.

2. In the field logbook note the presence of large pieces of metal on the ground surface, whether any other metallic debris is present, any large variations in topography that may occur nearby, and any buildings within 50 feet of the survey location.

3. Check the instrument battery for sufficient charge and test the instrument using manufacturer's procedures.

4. Examine the study area for background noise and background conductivities, as discussed above. Record observations in the field logbook.

5. Make a survey traverse with the EM instrument. Operate the instrument in both horizontal and vertical dipole modes according to manufacturer's procedures.

6. At each station, record the obtained conductivity value in the data logger or field logbook. Note the station number and coordinates.

7. Continue the above procedure for each station along the line. If two or more coil spacings or orientations are used at each station, make multiple readings at each station to ensure that each occupied stations is repeated for each coil orientation.

8. If hard copies of each line of data from the strip recorder are made, label or number all notations made on the record to correspond to notes made in the field logbook.

9. When a data logger is used, at the end of each day download data from the data logger to a computer for further analysis.

4.1.3 *Data Processing and Interpretation*

A standard procedure for processing and interpreting the EM data is described below.

1. Download collected data from the data logger or input them to the main computer from recorded field notes and process the data. Plot, and perhaps contour, data. Also plot features listed in steps 1-3 above.

2. Compare the results of all plots, and note variations in conductivity that may indicate the presence of subsurface anomalies. Remember to consider all possible sources of EM anomalies and the results of step 5 above.

3. Using borehole information and any other geophysical data as a reference, develop a subsurface conductivity model that is consistent with all available data.

4.2 Ground Penetrating Radar

4.2.1 *Introduction*

Ground penetrating radar (GPR) is used for mapping shallow geologic interfaces, shallow bedrock, voids in concrete or limestone, and buried pipeline or reinforcement bars. Because, under the right conditions, it can be used to delineate trench boundaries and bulk or drummed waste, GPR does have application in hazardous waste management.

GPR transmits electromagnetic pulses into the ground from an antenna near the surface. These pulses are reflected from a variety of subsurface interfaces back to a receiver. As the antenna is towed along a survey line, the GPR signals are processed and displayed on a graphic recorder. The display represents a two-dimensional continuous profile along the surveyed line, depicting time versus distance. The display is very similar to a geologic section, except that the record is a time section rather than a depth section.

Under favorable conditions, GPR resolves subsurface features extremely well. However, actual depth of penetration is highly site specific and depends on the near-surface soil conductivity. Highly conductive soils, such as clays, can reduce penetration to less than 3 feet. Less conductive materials, such as clean, well-sorted sandstone, can allow depth penetration of up to 30 feet.

4.2.2 *Survey Design*

4.2.2.1 Field Equipment

The following equipment is needed to complete a GPR survey:

- GSSI SIR System-3 or equivalent radar system (more advanced models can be used)
- Appropriate health and safety equipment
- Flagging
- Lath or wooden stakes

- Field logbook
- Black waterproof (permanent) pens
- Tape measure (at least 200 feet long) or, for relatively smooth surfaces, a measuring wheel
- Extra paper for profile recorder
- Extra styluses for profile recorder

4.2.2.2 Field Procedures

A standard field procedure for collecting GPR data is described below. Two preliminary steps must be completed first.

- Given the purpose of the survey, design appropriate field parameters such as orientation of lines or grid, grid spacing, frequency of antenna, and necessity of antenna shielding.

- Survey line endpoints and mark these locations in the field with wooden stakes or lath. Transfer line locations to the correct position on the base map(s).

Design of appropriate field parameters must consider the following.

- The antenna and associated transmitter frequency used must optimize both penetration depth and required resolution given the survey purpose. Typical frequencies are 80, 100, 120, 300, 500, and 1000 MHz. Higher frequency antennas allow greater subsurface resolution but lesser depth penetration. To optimize results, surveys should have at least two antenna frequencies available.

- In grid areas, intraline spacing affects resolution. A spacing of 3 to 50 feet is commonly used, but actual spacing must provide the resolution required.

- Site conditions will determine how the antenna is towed. The antenna can be towed directly on smooth terrain. For areas with significant vegetation or surface stones and rocks, the antenna may need to be suspended 6 to 18 inches above the ground, or carried in a plastic non-conductive wagon, to prevent damage to the antenna and the potential of collecting GPR data of questionable quality.

- Antenna shielding must be considered and selected based on site conditions. Surface features such as fences, power lines, and trees can appear as prominent reflections on the GPR record.

A standard field procedure for conducting a GPR survey is described below.

1. Review site utility plans and perform a field inspection along the proposed survey lines. Check for overhead wires, manhole covers, buried cables, buried gas line indicators, and cased monitor wells. Have Excavation Specialists confirm the presence of telephone and utility features. Note the features in the field logbook.

2. In the field logbook note the presence of large pieces of metal on the ground surface, whether any other metallic debris is present, any large variations in topography that may occur nearby, and any buildings within 50 feet of the survey location.

3. To the extent that it is possible, note the approximate moisture content and relative clay content of surveyed media, as these will affect the estimated GPR penetration depths.

4. Complete a test line using the manufacturer's procedures. Optimize the instrument settings to obtain data appropriate for the project goals. Specific recording parameters that must be optimized include, but are not limited to, the following:

    - Radar scan speed

- Signal range gain
- High and low pass filter settings
- Time range for recording
- Transmitter pulse rate
- Recording printer speed
- Antenna towing speed

5. Vary instrument settings during the test line to determine the optimum recording parameters. When possible, complete a test line over a known buried feature in the survey area to help optimize instrument settings and calibrate penetration depths.

6. Initiate a site survey traverse. Beginning at the GPR line endpoint, tow the antenna along the line, using optimum instrument settings and towing speed (as determined from the test line). Continue for the entire line and subsequent grid lines.

7. If hard copies of each line of data from the printer are made, label all notations on the record to correspond to notes made in the field logbook, including recording parameters.

8. Permanent copies of this GPR data must be retained digitally on tape or disk, or on hard copy plots.

4.2.3 *Data Processing and Interpretation*

Processing of GPR data is limited. Most GPR data is processed with the various instrument settings during recording.

Interpretation must consider all the potential sources of a GPR anomaly, including interfering reflections from both surface and subsurface cultural features, and must draw upon the interpreter's GPR experience. Using site surface data, borehole information (if it exists), and any other geophysical data, develop a subsurface model that is consistent with all available information.

4.3 Self-Potential

4.3.1 *Introduction*

Self-potential (SP) surveys measure ambient voltages and voltage variations within the ground. These small voltages are generated by subsurface fluids, heat, and/or ion flow. Recording these voltage variations and resulting SP anomalies can allow delineation of fluid flow in the vicinity of dams, reservoirs, wells, faults, or lined ponds, and in some cases subsurface contamination.

The SP method uses a record of the ambient voltage generated by subsurface currents between two electrode locations that are connected by a wire to a voltmeter. Restrictions on the types of electrodes and voltmeter used are critical to the success of the survey. Electrodes must be nonpolarizing to reduce or eliminate spurious potentials generated at the electrode-ground contact. A nonpolarizing state is achieved by immersing a metal electrode in a saturated solution of its own salt, such as a copper electrode immersed in a copper-sulfate solution. The voltmeter must have an input impedance sufficiently large to prevent significant current to be drawn from the ground during measurement. This is achieved by using a DC millivoltmeter with input impedance greater than 10^8 ohms.

Although the equipment and field procedures used for SP surveys are relatively simple, considerable care and effort are required for high-quality results. Data must be reproducible, sources of noise must be recognized, and appropriate data reduction methods are necessary to correct for electrode drift and polarization. SP data must be interpreted by experienced personnel who understand all potential anomaly sources.

In engineering applications, SP anomalies of interest are usually generated by flows of fluid or ions through a porous medium such as rock or soil. The fields generated by fluid flow are called electrokinetic (or streaming) potentials, and those generated by ionic flow are electrochemical potentials. The amplitude of SP fields generated by fluid flow in engineering targets may exceed 500 mV, although magnitudes of tens to hundreds of mV are more common. SP fields generated by ionic flow related to artificial sources, such as buried metal or pipelines, tend to be relatively large and easy to detect. However, fields generated by ionic flow caused by contaminant plumes tend to be small in amplitude and may be difficult to detect. Natural and manmade anomalies may be superimposed on target anomalies. The use of magnetic or electromagnetic measurements in conjunction with SP data can be very helpful in recognizing sources of SP noise due to buried metallic objects.

The procedures outlined below are for SP surveys being conducted along the ground or a surface of an engineered structure. It does not specifically address how to conduct SP surveys in ponds or fluid containment structures. Although the basic principles and procedures are the same, some logistical requirements for surveys in bodies of fluids must be designed for each individual project.

4.3.2 *Survey Design*

4.3.2.1 Field Equipment

The following equipment is needed to complete an SP survey.

- High impedance (10^8 ohms or greater) DC millivoltmeter (e.g., Fluke model 8020A)
- Minimum of five SP electrodes. Copper/copper sulfate electrodes (such as Tinker and Rasor Model 6B electrodes or their equivalent) have been documented as the most stable for engineering applications. Electrodes with different metal components must be approved by RMRS personnel before they may be used.
- Two reels with a minimum of 500 linear feet of small diameter (20 gauge) solid wire, and connector plugs. The length of wire required depends on the size of the survey grid; some surveys may require more wire per reel.
- One quart of saturated copper sulfate solution, or a solution appropriate for the type of electrode used
- Appropriate health and safety equipment
- Wood stakes or lath
- Garden tool sufficient to produce a 3- to 10-inch-deep small hole for electrode emplacement
- Tape measure at least 200 feet long; or, for relatively smooth surfaces, a measuring wheel
- Field logbook
- Black waterproof (permanent) pens
- Form OPS-PRO.104A, Self-Potential Survey Data Form (see Section 6.0, Documentation)

4.3.2.2 Field Procedures

A standard procedure for conducting an SP survey is described below. Two preliminary steps must be completed first.

- Select field parameters appropriate for the purpose of the survey (coverage of survey area, station spacing, surface soil conditions, position of base electrode, etc.).

- Survey the line endpoints and mark these locations in the field with lath or wooden stakes. Mark all remaining station locations based on the predetermined grid with an identifiable marker (such as lath or wooden stakes).

The following must be considered when selecting field parameters:

- The SP survey is conducted in a series of short loops from a fixed base station. Each loop begins with a base station reading, continues with SP readings at a number of stations along a predetermined grid, and ends with a final base reading. Duration of each SP loop should be no more than 35 to 50 minutes. Loops of this duration reduce uncertainties in drift corrections (see below).

- Conditions at the base station must be unlikely to change during the survey period, and background noise must be at a minimum.

- Spacing between stations determines the degree of resolution. A spacing of 5 to 50 feet is commonly used, but for small near-surface targets, spacing may be as small as 2 feet. The resolution required and overall survey objectives will determine the station spacing chosen.

- Three or more anomalous readings are required to define an SP anomaly.

- Topographic effects that can produce SP anomalies that are superimposed on target SP anomalies must be determined.

- The potential effect of natural fluctuations of the earth's magnetic field and telluric currents on SP readings must be considered. Effects of these fluctuations are removed by making electrode drift corrections relative to a fixed base location. Also to be considered are solar magnetic storms, which can make SP data collection difficult or impossible.

- The possible effect on an SP survey of background noise caused by cultural interference, such as overhead or buried power lines or steel-cased monitor wells, must be evaluated. High noise levels can make interpretation difficult and can mask significant anomalies. In some instances they can make data collection and interpretation impossible. Actual background noise must be considered when collecting and interpreting the SP data.

A standard field procedure for conducting an SP survey is described below.

1. Record the initial site information on Form OPS-PRO.104A.

2. Review site utility plans and perform a field inspection along the proposed survey lines. Check for overhead wires, manhole covers, buried cables, buried gas line indicators, and cased monitor wells. Have Excavation Specialists confirm the presence of telephone and utility features. Note the features in the field logbook.

3. In the field logbook note the presence of large pieces of metal on the ground surface, whether any other metallic debris is present, any large variations in topography that may occur nearby, and any buildings within 50 feet of the survey location.

4. To the extent possible, note the approximate moisture content and relative clay content of surveyed media, as these may affect electrode contact resistance. The clay content of surface materials at RFETS can vary significantly over short horizontal and vertical distances. Investigate nearby gullies and geological data from nearby boreholes.

5. Ensure that all electrodes are filled with saturated metal solution (for copper electrodes, use copper-sulfate solution).

6. Measure and record the reel wire resistance; an infinite reading indicates open wire.

7. Measure resistance between reel frame and end of wire to check for short circuits. If a short circuit is indicated, either make repairs or do <u>not</u> allow the reel to contact the ground during the survey.

8. Put two electrodes in an appropriate solution bath (copper sulfate for copper electrodes) and measure and record the voltage between the electrode pairs. This measurement ("Electrode Correction" on form OPS-PRO.104A) will be used to check the initial electrode polarization. Measurements should be made in the mV range of a voltmeter with a minimum of 1.0 mV resolution.

9. Install the base electrode at the base location. Dig a small hole in the moist soil underlying the surface soil. Do not add water to the hole. Ensure a good coupling between the ground and the porous electrode terminal by tamping the soil around the electrode. Tie off the end of the reel wire and attach it to the base electrode terminal Place a sun shade over the base electrode.

10. Install the measuring electrode within 1 to 2 inches of the base station and ensure a good ground coupling. Connect the positive lead of the meter to the measuring electrode and the negative lead to the connection on the reel, and read the SP measurement for the initial polarization of the base and measuring electrode. This measurement ("Tie-In Correction" on form OPS-PRO.104A) will be used as a basis for electrode drift correction for SP loops.

11. At an SP station, dig a small hole into the moist soil below the surface layer. Insert the measuring electrode and ensure good soil contact by tamping the soil around the electrode. Connect the positive lead of the meter to the measuring electrode and the negative lead to the connector on the reel. Shade the electrode from the sun.

12. Read the SP measurement on the voltmeter for 10 to 20 seconds to check for drift or telluric fluctuations. Obtain a stable average. Record the final value ("ΔV" on form OPS-PRO.104A) in mV with the proper polarity. Briefly measure and record the contact resistance between the electrodes using the appropriate kilo-ohms range of the multimeter.

13. Move to the next station and repeat steps 10-12.

14. After completing the survey loop, or after an elapsed time of 35 to 50 minutes, return to the base station and read the SP measurement at the base location in order to correct for electrode drift. Approximately four times throughout the day, remeasure the polarization between the electrodes in the solution bath when making a base tie.

15. Record all measurements and comments on form OPS-PRO.104A.

4.3.3 *Data Processing and Interpretation*

SP data reduction must eliminate all electrode drifts associated with telluric currents, polarization effects, temperature effects, and background noise. Drift corrections are made to the measuring electrode relative to the base electrode, which is assumed fixed. If a value has already been determined for the base, this "tie-in" correction must be included in the final corrected SP value for each measured station.

Most interpretations of SP data are performed qualitatively by preparing data profiles and contour maps and assessing the resulting anomalies. Interpretation shall consider all potential sources of a given SP anomaly and assess whether the anomaly is characteristic of the suspected target anomaly.

More sophisticated interpretation techniques can be employed, particularly when corroborative information exists such as borehole data or data from other geophysical techniques. These other techniques include geometric and analytical modeling. The use of these techniques must be evaluated for each project and approved by RMRS personnel.

4.4 Magnetic

4.4.1 *Introduction*

Magnetic geophysical surveys provide a rapid, noninvasive means of measuring the earth's magnetic field. The magnetic field strength and gradient at any location is due primarily to the earth's magnetic core, local geologic materials, and the latitude and longitude of the site of interest. Because of the solar magnetic field surrounding the rotating earth, a diurnal fluctuation in the magnetic field also occurs. A secondary magnetic field may arise from anthropogenic sources. These sources include adjacent surface ferromagnetic objects such as steel fencing and vehicles, subsurface objects such as utility lines or metal drain pipes, and overhead power lines.

Magnetic geophysical surveys measure the magnetic intensity (total magnetic field) at each ground survey station. The units used are gammas (γ), where $1\gamma = 10^{-5}$ gauss. Expected total magnetic field is approximately 50,000 γ. Magnetic anomalies may have an intensity of 50 γ or more. Magnetic noise originating from subsurface geologic materials may be approximately 5 to 10 γ.

Anthropogenic components shall be identified before beginning a survey. Data for total magnetic field shall be recorded using electronic data loggers. During field magnetic measurements, a fixed base station magnetometer will measure diurnal magnetic variation to provide compensation to the roving magnetometer data record. Field data will be downloaded to hard and floppy disks.

The following section specifies procedures for surface magnetic surveys using the EDA Omni magnetometer instrument or equivalent for both the tripod-mounted base station and the field-roving magnetometer.

4.4.2 *Survey Design*

4.4.2.1 Field Equipment

The following equipment is needed to complete a magnetic survey.

- Two EDA Omni magnetometers with integral data logger or equivalent
- Tripod
- Brunton compass or equivalent
- Fiberglass tape, 300 feet long
- Appropriate health and safety equipment
- Field logbook
- Black waterproof (permanent) pens
- Flagging
- Wooden stakes or lath

4.4.2.2 Field Procedures

A standard field procedure is described below. Five preliminary steps must be completed before a survey begins.

- Select the appropriate field parameters based on the purpose of the survey, whether the site contains areas of magnetic interference, on traverse spacing, direction of traverses, and magnetometer reading interval.

- The surface geophysical survey grid-traverse lines will be controlled from a surveyed baseline(s) provided by RFETS personnel. Grid traverse line endpoints will be marked with flagged lath or stakes at intervals, as designated in the work plan, along this baseline. The baseline and traverse line stations of the magnetic survey shall be transferred to the appropriate base map.

- The location of the magnetic base station will be selected after consulting site utility maps and performing a field inspection of the site to assure minimal magnetic interference from power lines, railroad tracks, fencing, vehicular traffic, subsurface utilities, air monitoring stations, or other metallic objects. The site shall be cleared with a portable magnetometer or by Excavation Specialists.

- The operator of the geophysical field instrument will check that personal articles such as watches, belt buckles, radios, clipboards, boots, etc. do not contain interfering ferromagnetic materials

- In areas, where required, an in situ gamma radiation survey will be conducted by RFETS personnel prior to designing or performing a magnetic survey.

Selection of the appropriate field parameters will be determined by the RMRS project manager with input from an experienced geophysicist or other experienced personnel. Parameters to be considered are:

- The height to suspend the magnetometer above ground surface.
- The spacing between adjacent grid-traverse lines along baseline.
- The spacing of stations along each grid-traverse line.
- Grid-traverse lines will be extended an additional 50 feet along significant anomaly indications. Where such anomalies are attributed directly to known pipelines, fences, or other visible and mapped anthropogenic ferromagnetic structures, the survey need not be extended.
- Definition of a magnetic anomaly requires three or more anomalous readings.
- Suspected anthropogenic interferences to the ambient magnetic field will be evaluated as to their mapped location and trend. Where utility line maps indicate pipelines and electric lines are present, the grid-traverse line will be oriented orthogonally where possible.

A standard field procedure for conducting a magnetic survey is described below.

1. Review site utility plans and perform a field inspection along the proposed survey lines. Check for overhead wires, manhole covers, buried cables, buried gas line indicators, and cased monitor wells. Have Excavation Specialists confirm the presence of telephone and utility features. Note the features in the field logbook and transfer their location to the appropriate map.
2. Note in the field logbook ferromagnetic objects observed on the ground surface.
3. Note in the field logbook variations in topography or the proximity to buildings.
4. Check the magnetometers and data loggers for sufficient battery charge, and test the instruments using the manufacturer's procedures.
5. Set up and initiate the measurement of diurnal magnetic field variation using the tripod mounted base station magnetometer and data logger.
6. Begin a site survey using the roving magnetometer along a traverse line. The magnetometer must be operated in accordance with the manufacturer's operating instructions for measuring total magnetic field and vertical magnetic gradient.
7. Check to determine if each magnetometer's measurements are being properly received and electronically stored in the data logger. Correlate the station number to the total magnetic and vertical magnetic gradient data entry with the grid location in the field notebook.
8. In the field logbook, indicate the date and time of the start and end of each traverse made with the roving magnetometer.
9. Continue the above procedure for each station along all traverse lines.
10. Label or number all notations on the field map corresponding to notes made in the field logbook.

11. Download daily the electronic data from the roving field magnetometer and from the base station magnetometer to a computer hard drive and to disk for further analysis.

4.4.3 *Data Processing and Interpretation*

A standard procedure for processing and interpreting the magnetometer data is described below.

1. Download collected data from the base station and roving magnetometers to the computer. Compensation of measurements of total magnetic field collected by the roving magnetometer are made using the record of diurnal variation measured by the base station magnetometer. The total magnetic field and vertical magnetic gradient data are then processed. Data are then plotted and contoured at the appropriate scale for the base map selected.

2. Process total magnetic field and vertical magnetic data using computer software with hardware capable of generating contoured colored maps.

3. Generate an archival-quality computer disk DXF file that can be used for CADD color plotting, girding, and contouring of the total magnetic field and vertical magnetic data at a selectable map scale.

4. Compare the results of the total magnetic field and the vertical magnetic gradient to determine if subsurface anomalies are present.

4.5 Time Domain Electromagnetic Metal Detection

4.5.1 *Introduction*

The EM61 time domain electromagnetic (TDEM) metal detection method developed in 1993 rapidly determines the existence of surface and buried metallic objects. The method is superior to the magnetic method because it is sensitive to all types of metals and not limited to ferromagnetic metals. By use of electromagnetic induction and a small transmitting coil, a time-varying current is produced. When this current is shut off, eddy currents are induced in the subsurface, both in conductive buried objects and the surrounding soils and fill materials. The receiver coils measure currents after they have dissipated in the soils but remain only in highly conductive buried objects. Thus, a TDEM metal detector, such as the Geonics EM61, can determine the presence of metallic objects in the subsurface and may also estimate their lateral extent and depth of burial, even in the presence of power lines and other cultural features.

This section specifies procedures for surveys using a TDEM metal detector such as the Geonics EM61. This instrument uses a single transmitter with a frequency of 75 Hz. A square current waveform is used with equal periods of on and off time. Measurements of secondary voltage are made and recorded in two coils spaced 40 cm apart at 450 microseconds after turn off. In addition, the x and y position of the measurement is recorded such that profiles or contours of the measured voltages can be constructed.

4.5.2 *Survey Design*

4.5.2.1 Field Equipment

The following equipment is needed to complete a TDEM metal detector survey:

- Geonics EM61 Metal Detector or equivalent
- Digital data logger
- Appropriate health and safety equipment
- Measuring tapes
- Wooden stakes or lath and environmentally safe marker paint
- Flagging

- Survey compasses
- Field logbook
- Black waterproof (permanent) pens

4.5.2.2 Field Procedures

A standard field procedure for conducting a TDEM survey is described below. Two preliminary steps must be completed before the survey begins.

- Select field parameters that are appropriate for the purpose of the survey.

- Survey the location of the baseline. Locate and survey the traverse endpoints at appropriate intervals along the baseline (to be determined in the field). Mark the grid coordinates on the wooden stakes or lath.

Selection of appropriate field parameters will consider the following:

- Spacing between stations determines the degree of resolution. A spacing of 10 to 100 feet is commonly used, but spacing as small as 2 feet can be used for extremely shallow targets or to aid in lateral resolution in very complex environments. The configuration of the measuring wheel and data logger of the EM61 easily allows spacing as small as 0.6 feet.

- In grid areas, spacing between traverse lines also affects resolution. A spacing of 5 to 15 feet is commonly used, and spacing as small as 2.5 feet is possible.

- Any reading above background defines an anomaly with the EM61. Background should be near zero. A single anomalous point reading can indicate a small metallic object near the surface. However, this one point may be insignificant within the scope of the project. Pin flags from previous surveys can cause an anomaly. More than three continuous readings above background may indicate an anomalous trench or pit that could contain metallic objects. The interpreter shall judge what anomalies are significant for meeting the survey objectives.

A standard field procedure for conducting a survey with the EM61 TDEM metal detector consists of the following:

1. Assemble and check instrument, battery, and function. The instrument is factory-calibrated and has an auto-null feature when the instrument is turned on. Because the instrument is very sensitive (it measures in nannovolts), the null reading can be plus or minus several nannovolts. The null reading shall be monitored by the operator during the survey.

2. Before beginning the survey, examine the proposed survey lines for any feature that could cause an anomaly, such as fences, surface metal, survey monuments, well heads, etc. In the field logbook, describe any such features, and plot their locations on the base map(s).

3. Begin the site survey traverse with the EM61 following the manufacturer's procedures. Establish line and station increments in the data logger and begin the collection of data.

4. The data is automatically recorded in the data logger and shall be visually monitored by the operator. A summary of the traverses surveyed shall be maintained by the operator or an assistant in the field logbook and plotted on the base map(s).

5. Data stored on the EM61 data logger shall be downloaded to a PC computer when the memory is full or at the end of a survey session.

6. Compare line and station coverage in downloaded data files and in notes. Correct errors in line numbers or station numbers. Document in the field logbook any errors that are found and the corresponding corrections.

4.5.3 *Data Processing and Interpretation*

A standard procedure for processing and interpreting the EM61 data is described below.

1. Input downloaded data into a data handling program. Check the data for validity by examining the appropriate data statistics, then enter the validated data into a data processing program that can construct profiles or contour maps. Construct preliminary maps on a computer monitor and visually check them for validity. If data errors are noted, correct them at this time in the handling program or, if necessary, repeat data collection in the field. Document in the field logbook any errors that are corrected.

2. If necessary, apply decorrugation filters to remove corrugation effects caused by alternating direction of line survey.

3. Construct final data maps (usually in the form of contour maps). If necessary, produce individual detailed maps of each identified anomalous area.

4. Identify lateral extent of each anomalous area on a base interpretation map.

5. If available, use the appropriate algorithms to construct depth to top-of-object maps of anomalous areas.

Write a report that describes the following:

- Field procedures
- Interpretation techniques
- Results
- Location of anomalous areas
- Interpretation of these anomalous areas

5.0 DECONTAMINATION

Personnel involved with surface geophysical surveys will follow all decontamination procedures as outlined in the appropriate Health and Safety Plan. Geophysical equipment which has been in contact with potentially contaminated ground surfaces will be decontaminated according to procedures outlined in SOP OPS-PRO.127, General Equipment Decontamination, and any appropriate procedures specified in the Health and Safety Plan.

6.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by personnel engaging in these activities. Field observations and data will be documented in the field logbook. Completed decontamination activities will similarly be noted. The date of the manufacturer's most recent calibration and certification will also be documented, if this information is available. Observations, data, and other pertinent information will be recorded with black waterproof (permanent) ink in a bound field logbook having consecutively numbered pages. Data and observations collected during SP surveys will be documented on the Self-Potential Survey Data form (Form OPS-PRO.104A).

7.0 REFERENCES

7.1 <u>Source References</u>

The following references were reviewed before this procedure was written:

Corwin, R. F., 1990, Applications of the Self-Potential Method for Engineering and Environmental Investigations, *Symposium on the Application of Geophysics to Engineering and Environmental Problems, Golden, Colorado, 1990.*

Corwin, R. F., and D. K. Butler, 1989, *Geotechnical Applications of the Self-Potential Method; Report 3; Development of Self-Potential Interpretation Techniques for Seepage Detection*, U.S. Army Corps of Engineers Technical Report REMR-GT-6, Washington, D.C.

McNeill, J. D., 1980, *Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers*, Technical Note TN-6, Geonics Ltd., Canada.

U.S. Environmental Protection Agency (EPA), December 1987, *A Compendium of Superfund Field Operations Methods*, EPA/540/P-87/001.

U.S. Environmental Protection Agency (EPA), October 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*. Interim Final. EPA/540/G-89/004.

U.S. Environmental Protection Agency (EPA), May 1989, *RCRA Facility Investigation Guidance*, Interim Final.

7.2 Internal References

Related SOPs cross-referenced by this SOP are as follows:

- SOP RMRS/OPS-PRO.127, General Equipment Decontamination
- SOP RMRS/OPS-PRO.102, Borehole Clearing

U.S. DEPARTMENT OF ENERGY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

FORM OPS-PRO.104A (Rev.0)

SELF-POTENTIAL SURVEY DATA

Date: ______________________
Location: ______________________
Line: ______________________
Base Electrode Location: ______________________
____
____
____
Operator: ______________________

Project Name: ______________________
Voltmeter: ______________________
Base Electrode: ______________________
Portable Reference Electrode: ______________________
Measuring Electrode: ______________________
Reel Checks: Resistance: ______________________
Short Circuits: ______________________
General Site Conditions: ______________________
____

Time	Station	ΔV Measured (mV)	Resistance (Kilo-ohms)	Electrode Correction (mV)	Tie-In Correction (mV)	ΔV Corrected (mV)	Comments

Completed By: ____
Print Name   Signature   Date

Subcontractor: ____